What is going up in smoke?
--A study of emissions in the wood industry

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Abstract: The requirements that a business needs to consider when building a wood panels manufacturing plant are much the same as they have been for decades, but today there is also the need for multiple environmental studies and permits. These are costly and time consuming additional expenses that often are the longest lead-time items on any project. Most industrialized countries have legislation in place to limit and control the negative impact that emission of pollutants may have on the environment. This paper discusses what is actually happening inside wood drying plants, and the prerequisite conditions for genesis of pyrolytic products relative to the operational parameters, such as choice of input raw materials, driers design and operational regime, choice of fuels for the heat generation and how these factors influence production of stack emission. The characterization of emission condensate by analytical methods is described, and survey of emission control system in use worldwide is described, and means of investigating what may be the optimum design for the control of emission is discussed. Alternate uses of utilizing the condensate, other than burning, are presented for consideration.

Keywords: Wood drying; Pollution; Emission analysis; Emission control; Alternate usage

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Introduction

Historically, when a wood panels manufacturing plant was built, it needed capital, a convenient location, source of raw materials and a market for the finished product. Today it still needs the same and, in addition, it needs multiple environmental studies and permits. These permits are costly, time consuming and at times the longest lead-time item on any project. Most industrialized countries have legislation in place to limit and control negative impact that emission of pollutants may have on the environment. In the USA the allowable emission level from wood particle drying plants, such as MDF and particleboard is 50 $mg \cdot m^{-3}$. West European countries have the similar emission levels to protect environment. In Australia, emission limits are subject to state legislation, New South Wales (NSW) permits emission of particulate matter of 250 $mg \cdot m^{-3}$ and in Queensland the limit is 450 $mg \cdot m^{-3}$. There is no specification to limit the emission of condensable organic matter and non-condensable volatile compounds. It is the presence of these organic compounds that causes 'blue haze', a 'tell-tale' of air pollutants in the air. It is expected that Australia will adopt more stringent Clean Air control measures in line with the practices overseas. The 1990 Clean Air Act (CCA-'90) of the USA provides a useful guideline. Previous Clean Air limits in New Zealand mirrored those of NSW, permitting emission of particulate matter up to 250 $mg \cdot m^{-3}$. Having no developed standards for measurements and monitoring of air quality, New Zealand is using measuring methods of Standards Australia. The Resource Management Act (of 1991) has repealed the Clean Air Act (of 1972) and has placed the control of the legislation in the hands of the local council who will determine the acceptable limits. The industrial establishments when renewing their operating licence now have to present to the council their proposed limits and the nature of emission from their plants, and the new limits will be set. Practically the entire reconstituted wood panels industry in Australia is based on utilizing softwood sawmilling wastes and plantation thinning. Nearly 1 000 000 tons of panel products, consisting of particleboard, medium density fiber board (MDF) and hardboard are produced annually. *Pinus radiata* and to a lesser extent *Pinus elliottii* are the main softwood species used in the wood panels manufacture. During the drying process a material loss of about 4% (OD basis) occurs. This loss represents a mixture of wood fines that are carried by the air stream past the cyclone collectors, a range of terpenoids that have either evaporated or steam distilled from the wood particles during the drying process, and products of partial pyrolysis that occur in small wood particles in contact with hot combustion gases issuing from the drier burners. The initial contact temperature may be as high as 500°C. Effluents from the wood panels drying plants are released into the atmosphere, and are often responsible for the formation of 'blue haze'. Clean Air legislation will certainly limit the emission levels of the drying plants in the near future, necessitating the implementation of emission control measures. (D. Torner, CSR Australia, personal communication). Wet-dry electrostatic precipitators adjacent to the wood particle drying plants recover stack condensate of approximately 0.5% w/w (OD wood basis). An average particle board plant is processing100 000 tons of product, and is expected to yield some 500 tons of terpenoid and pyrolysis by-products annually.

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Origin and diversity of terpenoids

The biochemistry and the mobilization of terpenoids in the woody species is poorly understood, but it is clear that the presence of these substances plays an important role in the defence and resistance of the plants and the environmental interaction of forest trees and their predators and parasites (Shrimpton 1978; Raffa and Berryman 1982). Conifers produce amounts and types of terpenoids that are without a parallel in the nature. The terpenoids are derived by the formal condensation of C5 isoprenoid units and they range from the volatile monomer isoprene (C5) to the polymer rubber (MW-10 000 000). All plants use the same isoprenoid pathway in the process of synthesis of the essential substances, such as phtylol (C20), carotenoids (C40), dolichol phosphate (C100), steroids (C27), prenylated quinones and plant hormones (C15, C20) In the narrow range of species exist a diverse range of other terpenoids, classed as secondary metabolites, often stored in large quantities in the specialised compartment of a tree, offering ecological advantages to the species that accumulate them (Gibbs 1974; Seigler 1981a, b; Langenheim *et al* 1981). The terpenes are the most diverse group of wood extractives, but lend themselves to a simple classification by size.

The monoterpens (C10) consist of two main groups: the lipophylic, steam-volatile constituents of essential oils, and the hydrophylic, non-volatile iridoid glycosides. The sesquiterpens (C15) encompass a wider range of skeletal types and oxidation states than those are usually found in the monoterpens (ie. furans, lactones) and are usually contained in the higher fractions of the essential oils. The diterpenes (C20) occur mainly as non-volatile resin acids, and lactones, but include some volatile hydrocarbons such as cembrene and rimuene. The triterpenes (C30) with the exception of their acyclic precursor, squalene, occur as C30 oxygenated polycyclic compounds. The triterpenes are non-volatile and often appear as glycosylated derivatives or saponins. The polyterpenes are long-chain acyclic alcohols (polyprenols) and polyisoprene polymers of a very high molecular weight (eg. rubber, gutta, chicle). Terpene accumulation has been observed in every plant organ in the variety of physical forms, including oils, resins, gums, latex and waxes (Dell and McComb 1978), and taxonomic distribution of terpene-accumulating plants has been the subject of extensive reviews (Gibbs 1974; Seigler 1981a, b). Bark extractives are similar to the extractives derived from wood.

Classical terpene extractives

Since ancient times naval stores industry has been the largest processor of terpene wood extractives, for the variety of end uses, including waterproofing of wooden ships. (Zinkel 1981). Presently, conifer rosin (non-volatile terpenes) and turpentine (essential oil) are used to manufacture a wide range of industrial products, solvents, adhesives, polymers, emulsifiers, coatings and paper sizing (Weaver 1982). The primary sources of these oleoresins are *Pinus palustris*, *Pinus elliotti* in the USA and *Pinus sylvestris* (Scots pine) in the former USSR and in Northern Europe (Koch 1972). The main commercial process for collection of oleoresins is derived from chemical stimulation of new resin flow from pulpwood or from the living stumps. Flow of resin is stimulated by administering paraquat-type herbicides in sublethal doses. Paraquat is effective in stimulating the resin production only in pines. The monoterpenes, alpha- and beta-pinene are used for production of specialty chemicals (Zinkel 1981; Weaver 1982).

Partial pyrolysis products

Drying process in a typical flake drier irrespective of the layout is designed to remove moisture from wet material in a short period of time, from 100%-120% to final M.C. of 2%-3%. Present technological processes to manufacture particleboard product dictate harsh drying conditions in the driers. Most commercial adhesives, urea-formaldehyde, urea-melamine-formaldehyde and phenol-resorcinol -tannin-formaldehyde require high core curing temperatures. Additionally, water is produced as a product of condensation-polymerisation reaction of the adhesives, necessitating that the furnish moisture content be about 2%. The residence time for flake drying varies from 2-5 min, and the temperature gradient for the hot direct combustion gases is from about 500°C at the point of flake-hot gas contact to 140-150°C at the drier's exhaust. At the same time the wood flakes have been heated from ambient temperature to above 100°C It is probably that small wood particles undergo chemical changes would occur, while much larger particles are dried to 2% M.C., inside a drying system. Products of pyrolysis are found in the stack condensate, accounting for as much as 80% w/w of the total condensed mass. Relatively low temperatures in the flake dryers will be more conducive for production of pyrolytic oils rather than wood gasification, that normally takes place at elevated temperatures, above 700°C.

Drying conditions variables

No two particle board manufacturing plants are identical in design, equipment specification, raw material composition, fuels and subsequent forming and pressing processes. Removal of water from wood flakes is dependant upon contact of wet flakes and hot gases issuing from the furnace, flake size and thickness, wet flakes moisture content, drier inlet temperature, drier exhaust temperature, particle residence time and tumbling effect. Many plants have undergone throughput increase modifications. In most cases it meant increasing the drier inlet temperature, by stoking the furnace with more fuel.

a. *Initial moisture content of wood flakes.* Drier rating is expressed in the amount of water that the device is capable of removing from the material that is being dried, and the

amount of water present in the wood flakes will determine main drying parameter. The variations extend from a 'dripping' green wood particles containing up to 160% of water, in wet cold winter periods, to planer mill shavings that have been kiln dried, containing 15% of water. Intermediate situations may include combination of raw material sources, sawdust, round wood, recycle particles and sawmill woodchips and seasonal weather variations. Since every plant manager is desirous of a steady material flow through the manufacturing process, the driers will be inherently operating under variable conditions to supply steady output of dry flakes, coping with feedstock differences.

b. *Drier throughput.* Most flake driers are designed for water evaporative capacity between 3 000-7 000 $kg \cdot hr^{-1}$. The rated drier performance can only be enhanced by increasing inlet temperature. Depending on type and design, these may range from 250°C to 500°C. Theoretically, wood particle temperature should not rise until all free and bound water is removed, but particle size non-uniformity can cause wood fines to dry rapidly and starting to pyrolyse in the ambient of hot oxidizing gases. Obviously then, when drier performance is being increased, wood fines will dry more rapidly and partial pyrolysis is more likely to be a side reaction.

c. *Drier design.* The drying process efficiency is measured in energy requirement to remove 1 kg of water, which is in the range of 750-1 000 kcal, depending on the design of the drier. Particle board driers may be classified according to the working principle into the following types: rotary drum driers, tube bundle driers; multiple band driers; contact driers; turbo driers; burned waste gas stream driers; suspension type driers. High inlet temperature is the feature of older designs; rotary drum and tube bundle triple pass driers, compared to more recently developed driers; contact, jet and suspension types.

d. *Types of fuel.* At best particleboard manufacturers are 'scavengers' of wood materials, lagging behind other wood based industries, sawmilling, plywood, pulp and paper and MDF, in choice of raw materials. Current furnace and drier designs reflect the industry's frugality. Manufacturing processes for particleboard can only be profitable if the energy requirements are met by using own residues for drying and pressing. A generation ago, oil or gas was the chief energy source. With oil prices climbing most furnaces and driers were converted to run on wood waste. Conversion was not always an optimum realization. Choice of fuel will be reflected in type and quantity of stack emission. Fuel with high ash content will result in high content of large particle emission >10 μm. Sander dust will also contribute to high particulate emission, complicated with the presence of adhesives, abrasives and waxes. When sander dust contributes more than 30% of the fuel needed to power the drier, particulate emission exceeds the NSW limit of 200 $mg \cdot m^{-3}$. Some plants burn bark as the principal fuel. Bark fuel is characterized with high mineral content (2%-3%), high tannin content (more than 20%) and low cellulose content. Unless furnace temperature is very high (above 1 200°C) and flue gases recirculated for afterburning, it is expected that stack emission will result in tarry resinous substances, derived chiefly from incomplete decomposition of lignin and tannin macromolecules.

e. *Particle size.* Prior to the arrival of MDF technology, and when sawmilling waste was not an issue of concern, primary source for particleboard flakes was plantation thinning roundwood. Flakes produced by flaking wood billets on drum flakers were uniform in shape and more importantly in thickness. Changes in the industry over the past two decades made it an imperative to consider lower grade and less uniform raw material, such as sawmilling waste slab and sawdust (which is also getting finer with use of finer gauge bandsaws), planer mill shavings, sugar mill residues and agricultural residues such as straw and flax. During drying small particles will dry faster owing to greater surface/mass ratio and reach 'bone-dry' condition before larger particles. It is conceivable that pyrolysis process will initialise on the surface of these fines.

Projected usage of terpene extractives

Inherent biological activities render the interest of terpenes to the pharmaceutical industry. Terpenes are attractive material for synthesis of complex chemicals and biological reactants. Natural terpene extractives and their derivatives are also used as agricultural pesticides and even hormonal preparations (Silverstein 1981; Norin and Winell 1971). Monoterpens can also be used as combustible hydrocarbon fuels. About 40 liters of sesquiterpene mixture per tree per year can be obtained from *Copaifera multijuga* (Leguminosae). The future prospects of the terpene extractive industry will depend on finding new ways to stimulate production and on developing new markets. Significant contribution may be made by condensing the oleoresin fraction in the wood panels drying plants effluents. The development of new plants with desired traits of productivity and environmental adaptability should have considerable impact in providing the full range of terpenes necessary for commercial use (Calvin 1983; Farnum *et al.* 1983).

Characterization and composition of drier stack condensate

Considering the coniferous nature of particle board raw material, it might be reasonable to assume that the composition of the condensate would reflect the composition of volatile terpenoids in wood. This is not exactly the case. While terpenoids were identified in the stack condensate, the bulk of the condensate originated from incomplete combustion in the furnace and the pyrolysis within the drying process itself. Hundreds, possibly thousands of various derivatives can be identified in the condensate, when adequate pre-separation is carried out prior to analytical processes. There are only two sources of condensate resins available in the region of Australia and New Zealand,

and both are in New Zealand, from two electrostatic precipitators installed by Fletcher Wood Panels to their driers in Kumeu and Taupo plants. The two plants are very different in drier design, furnace design, fuels, raw material, and the operating temperatures. To date, only samples from Taupo plant have been investigated;

a. *Condensate form.* The condensate after leaving wet-electrostatic precipitator (E-Tube) can be in the form of sediment, (particles heavier than water), suspension (particles mixed with water in suspension), and floating resin (particles lighter than water) and foam. Floating resin is a black tarry substance, having specific gravity -0.9 and pH ranging from 11-13, resulting from sodium hydroxide dousing of the E-Tube.

b. *Solubility.* The condensate is partially soluble in most solvents, being almost completely soluble in strongly polar solvents; (MeOH and EtOH), some 75% soluble in petroleum ether, about 60% in chloroform and ether. Non-soluble residue, presumably charred wood particles and ash accounted for some 6% of the condensate.

c. *Steam/water distillation.* A 50-g sample was steam/water distilled. Only few droplets of oleoresin distillate were collected after 8 h of distillation. The resin is largely non-volatile.

d. *Fractional distillation.* At atmospheric pressure a 50-g samples yielded only few droplets below 150°C. Temperature rose rapidly to 240°C. with little or no evaporation. Thermal degradation was observable above 200°C. Vacuum distillation yielded marginally more distillate and thermal degradation was also observed.

e. *Moisture content.* After drying a sample at 103°C. overnight, a weight loss of 20.5% was recorded, presumably water and some volatile matter.

f. Resin acids. Acids were precipitated according to the method for isolation of resin acids by addition of cyclohexylamine. A hard resinous precipitate accounted for 24.0% of the condensate.

g. *Free fatty acids.* The FFA was extracted with 1M NaOH as an aqueous solution of Na-salts of FFA and precipitated with 2M HCl. Yield was 4.5%.

h. *Neutrals.* The residue was evaporated to dryness, yielding 42%.

Summary	
Non-soluble residue	6.0%
Moisture and volatiles	20.5%
Resin acids	24.0%
Free fatty acids	4.5%
Neutrals including phenols	41.0%
Losses	4.0%

Possible uses of condensate products

It was a concern for the environment and air quality that gave rise to the installation of pollution interceptors such as the E-Tube in the first place, and handling of condensate is considered an additional task. Most managers would be quite happy with just a neat disposal of this by-product, but in some cases, it just would not go away. Blockages, foaming and down-time are some of the problems experienced with this ungainly substance. There is a need for improvement of the technology that will make the handling easier, non-interfering with the production scheduling and possibly recyclable into the end product.

a. *Water repellent additive.* Paraffin wax is routinely added to particleboard and MDF to reduce the surface water absorption and swelling. Adding 0.8%-1.5% of wax to the board improves water absorption properties quite significantly, but further addition does not seem to make much difference. Isolated resin acids are hard, waxy and have high boiling points appear to have good water repelling properties, and resin coated surface resists wetting by water. It is quite possible to use the resin acids fraction as a replacement for paraffin wax.

b. *Phenol resin compatible extender.* Structural particle board used for flooring and other structural purposes is bonded by phenolic or tannin resin. In either case, the adhesive is dark brown coloured, resulting in dark coloured particleboard. Significant portion of the condensate resin is composed of derivatives of lignin and tannins from wood, having -OH group. It is conceivable that extending of phenol or tannin adhesive with phenolic fraction of the condensate would not adversely affect the bonding, resulting in some saving.

Emission control

There are four main types of emission from particle board drying plants: 1) Large solid particles, >10 μm; 2) Small solid particles, <10 μm; 3) Small volatile organic particles, evaporated from the drying furnish; 4) products of partial pyrolysis in the furnaces and driers.

Selection of emission control systems

Criteria for selection of emission control systems will depend on what regulation is to be met and the degree of control.

1. What regulation is to be met?
2. What classes of particles need to be controlled to meet the regulation?
3. Capital and operational costs of each option.
4. Space requirement
5. Energy requirements
6. Safety aspects; fire, explosion, chemical pollution.

Commercial emission control systems

Generally, effectiveness of dust particles separation from the gas stream is dependent on particle size, aggregate state (solids or liquids), specific gravity of particles (denser particles are easier to remove), electrostatic properties and solubility in gases or liquids. It is known that the drying conditions vary from one plant to another and it would be difficult to recommend a single separation system that would be equally effective in every situation.

1. *Wet scrubbers.* In conjunction with water recirculation system, secondary and multiple cyclones, wet scrubbers are quite effective in removing solid particles larger than 1.0 μm. It is in sub-micron condensable particle range that these devices lack effectiveness. Coupled however, with electrostatic separators as preliminary collectors, these devices perform well cooling gases and separating larger particles.

2. *Fabric filters and bio-filters.* Fabric filters are normally used to filter dust particles from the gas stream. The system would unsuitable for removal of tars and resins.

3. Sonic agglomeration devices. These devices use ultrasonic waves to align and precipitate particles out of the gas stream. Relatively high power requirement is a general characteristics of the system and handling of tarry substances is not well defined.

4. *Centrifugal collectors.* A number of collectors in which the centrifugal field is provided by a rotating member are commercially available. Often, the exhaust fan and dust collector are combined as a single unit. The effectiveness of these units is comparable to cyclone type separators. Again, formation of tar deposits would affect adversely the performance of the separators.

5. *Venturi scrubbers.* These devices are very popular in number of applications and the basic designs vary in regard to method of achieving the venture effect, wet or dry approach and the entrainment separator. Tarry build-up would also inhibit the optimal performance, as tar removal from the separator would prove troublesome. Some designs also demand high-energy input. Efficiency of removing particles is best for particles above 1.0 μm in size.

6. *Electrostatic separators.* These devices are capable of removing small particles 0.1 μm to 1.0 μm from the gas stream. Developed primarily for the needs of mining industry as a method for beneficiation of minerals from sands, the electrostatic separators are used in food industry and in waste management. Geoenergy of USA has developed a electrostatic precipitator, the E-Tube and some 50 units have been installed to control emission from wood drying plants, two at Fletcher particle board in New Zealand. The precipitators are effective in most situations, with the exception of emission containing tars.

Conclusions

The direction of this research is aimed at the following aspects of wood panels processing activities:

1. Gain a clearer understanding of what is actually happening inside wood drying plants, including the prerequisite conditions for genesis of pyrolytic products relative to the operational parameters, such as choice of input raw materials, driers design and operational regime, choice of fuels for the heat generation and how these factors influence production of stack emission, qualitatively and quantitatively. This aim will be achieved through observing and monitoring existing plants in operation aided by a simulation model of drying wood particles based on varying conditions of drying.

2. Characterization of emission condensate by analytical methods, such as column chromatography, standard methods of preparative organic chemistry, determination physical properties, mass spectroscopy, IR spectroscopy, HPLC etc.

Survey of emission control system in use and investigation of what may be optimum design in order to control emission effectively. Handling of condensate by chemical and engineering means may be improved with better understanding of its composition and behavior.

Investigate feasibility of utilizing the condensate other than burning, preferably in wood panels manufacture, as water repellent additive and adhesive extender.

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